10/509509

The Patent Office

PATENTS • DESIGNS • COPYRIGHT • TRADE MARKS

REC'D 1 APR 2003

WIPO PCT

PCT/GB 2003 / 001284

28 SEP 2004

#2

INVESTOR IN PEOPLE

PRIORITY DOCUMENT

SUBMITTED OR TRANSMITTED IN COMPLIANCE WITH RULE 17.1(a) OR (b)

The Patent Office
Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

I, the undersigned, being an officer duly authorised in accordance with Section 74(1) and (4) of the Deregulation & Contracting Out Act 1994, to sign and issue certificates on behalf of the Comptroller-General, hereby certify that annexed hereto is a true copy of the documents as originally filed in connection with the patent application identified therein.

I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

In accordance with the rules, the words "public limited company" may be replaced by p.l.c., plc, P.L.C. or PLC.

Re-registration under the Companies Act does not constitute a new legal entity but merely subjects the company to certain additional company law rules.

Signed K Behan

Dated 1 April 2003

BEST AVAILABLE COPY

tents Act 1977
ule 16)

THE PATENT OFFICE
A
28 MAR 2002
RECEIVED BY FAX

Patent Office

1/77

28MAR02 E707451-1 D02819
P01/7700 0.00-0207370.8

The Patent Office

Cardiff Road
Newport
South Wales
NP10 8QQ

Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

1. Your reference — C468.00/U (handwritten: 1125)

2. Patent application number *(The Patent Office will fill in this part)* — 0207370.8 — 28 MAR 2002

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

The University Court of the University of St Andrews
College Gate
North Street
St Andrews
Fife, KY16 9AJ

Patents ADP number *(if you know it)* — 404941 7001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention — Medical Imaging Apparatus

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

~~Keith W Nash & Co~~
~~90-92 Regent Street~~
~~Cambridge~~
~~CB2 1DP~~

CRUIKSHANK & FAIRWEATHER
19 ROYAL EXCHANGE SQUARE
GLASGOW G1 3AE

51/77
1-2-03

Patents ADP number *(if you know it)* — ~~1206001~~ — 5N4002

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* **the or each application number**

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
c) any named applicant is a corporate body.
See note (d))

a) Yes

0032716 28-Mar-02 03:50

9. Enter the number of sh[illegible]or any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	17
Claim(s)	–
Abstract	–
Drawing(s)	10

10. If you are also filing any of the following, state how many against each item.

Priority documents	–
Translations of priority documents	–
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	–
Request for preliminary examination and search *(Patents Form 9/77)*	–
Request for substantive examination *(Patents Form 10/77)*	–
Any other documents *(please specify)*	–

11. I/We request the grant of a patent on [illegible]

Signature Keith W Nash & Co Date [illegible] 02

Keith W Nash & Co, Agents

12. Name and daytime telephone number of person to contact in the United Kingdom

David L Roberts - 01223 355477

Warning

After an application for a patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977. You will be informed if it is necessary to prohibit or restrict your invention in this way. Furthermore, if you live in the United Kingdom, Section 23 of the Patents Act 1977 stops you from applying for a patent abroad without first getting written permission from the Patent Office unless an application has been filed at least 6 weeks beforehand in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction has been revoked.

Notes

a) *If you need help to fill in this form or you have any questions, please contact the Patent Office on 0645 500505.*

b) *Write your answers in capital letters using black ink or you may type them.*

c) *If there is not enough space for all the relevant details on any part of this form, please continue on a separate sheet of paper and write "see continuation sheet" in the relevant part(s). Any continuation sheet should be attached to this form.*

d) *If you have answered 'Yes' Patents Form 7/77 will need to be filed.*

e) *Once you have filled in the form you must remember to sign and date it.*

f) *For details of the fee and ways to pay please contact the Patent Office.*

C485/U

Title: **Medical Imaging Apparatus**

Field of the Invention

This invention relates to medical imaging apparatus for imaging subcutaneous body temperature within a body.

Background to the Invention

Medical imaging using infrared imaging or thermography to obtain passive and non-invasive measurements of human body temperature are established techniques. Infrared imaging only effectively measures the surface temperature of the body since infrared radiation does not penetrate body tissue very well and it is difficult to ascertain sub-surface temperature distributions accurately from such surface temperature measurements.

Microwave thermography is often used where tissue temperature at depth within bodies is to be measured. Since microwaves can travel further through body tissues, microwave thermography can achieve measurements to a depth of several centimetres. Typically this is done using a radiometer operating at a frequency of around 2-3GHz. Whilst temperature contributions are detectable at depth, spatial resolution is poor due to the relatively long wavelengths.

Summary of the Invention

In accordance with the first aspect of the invention, there is provided medical imaging apparatus for imaging subcutaneous body temperatures, the apparatus comprising detector means sensitive to incident millimetre wave electromagnetic radiation and for generating an output representative of said image, collector means for collecting such radiation travelling from a selected area of a body to be thermally imaged to the collector means

along a collection path and directing said radiation onto the detector means, the apparatus further comprising scanning means to cause said path to rotate, thereby to scan said selected area over the body (or region thereof) to be thermally imaged.

Millimetre wave radiation has been found to give rise to relatively high resolution images at depths of a few millimetres beneath the skin surface. The facility for rotating the collection direction enables the body (or part of body) to be imaged to be relatively rapidly scanned. Rotation can be achieved using continuously rotating components which are less prone to the inertial problems associated with components that create other types of scan, for example a raster scan.

Preferably, the apparatus includes focussing means for focussing the detector means on said area, wherein the focussing means is such as to give the apparatus a sensitivity profile, across the collection path, which is defined along the entire path length.

The defined sensitivity profile can be advantageous for imaging apparatus which does not have a rotatable collection path associated with it, and according to a second aspect of the invention, therefore, there is provided medical imaging apparatus for imaging subcutaneous body temperature, the apparatus comprising detector means sensitive to millimetre wave electromagnetic radiation incident thereon, and focussing means for focussing millimetre wave radiation travelling along a collection path from an area on a body to be imaged to the apparatus, wherein the focussing means is such as to give the apparatus a sensitivity profile across the collection path which is defined along the entire length of the path.

In this context, the sensitivity profile is defined in that its general form is known along the whole of the collection path. One example of is such a general form of profile is a fundamental Gaussian profile. The collector and/or focussing means can be considered to act as an antenna. As the result of the reciprocal nature of antennas, the sensitivity profile corresponds to the antenna beam pattern so that, were the detector means to be replaced

with a signal source or emitter for the antenna means, the apparatus would emit along the collection path a beam having a fundamental mode Gaussian intensity profile.

The use of a defined sensitivity profile improves the spatial resolution of a thermal image as that radiation received from the area on which the device is focussed will have propagated through body tissue in a well controlled and definable pattern.

Preferably, the collector and/or focussing means comprise a corrugated feedhorn and a wave guide for supplying radiation to the detector means, the feedhorn being arranged to convert a fundamental Gaussian mode beam of radiation, created by the collector and/or focussing means, into a wave guide mode in which it propagates through the wave guide to the detector means, the feedhorn thereby achieving the fundamental Gaussian mode sensitivity profile.

Alternatively, the apparatus may have Bessel sensitivity profile and to that end may include an axicon (i.e. a cylinder formed with a conical prism at one end).

Preferably, the collector means and focussing means are operable repeatedly to sweep the collection path through 360°.

To that end, the collector means may to advantage comprise a deflector which is rotatable about one axis to scan the collection path in a scanning direction across a body. The apparatus can further comprise line indexing means for moving the collection path in a direction perpendicular to the scanning direction.

The indexing means may move the deflector linearly along said axis or may comprise means for swinging the deflector about a second axis perpendicular to the first axis.

The latter arrangement avoids the need to move the whole of the imaging apparatus relative to the body in order to scan the portion of the body to be imaged.

Preferably, the apparatus further comprises isolation means, situated, in use, in the path of collected radiation to the detector means, for preventing signal leakage from the apparatus into the collection path.

This feature is particularly helpful if the apparatus is used on close range subjects. The isolation means prevents leakage of radiation from the apparatus, which when relfected back off the target could degrade the sensitivity.

Where the apparatus includes a feedhorn, the isolation means may be interposed between the feedhorn and the detector means or in front of the horn.

The latter is particularly preferred as it is easier to achieve low insertion loss over a wide band width, which is necessary for good thermal sensitivity.

Preferably, the apparatus is operable to form an image from emitted radiation in the frequency range of 10-100GHz and more preferably 20-40GHz

The apparatus is preferably sensitive to radiation of a plurality of different frequencies. This enables the apparatus to resolve areas of thermal emission in three dimensions.

Preferably, the apparatus includes calibration load means for emitting millimetre wave radiation at a pre-determined intensity, the apparatus being operable to direct said radiation to the detector means to enable the apparatus to be calibrated.

Where a collection path is rotatable, said load means may to an advantage be positioned as to lie in a line swept by the collection path so that the apparatus can be calibrated for each individual sweep.

Preferably , the load means comprises two loads and means for maintaining them at different temperatures, preferably straddling the range of subcutaneous body temperatures to be imaged.

If the detector means is linearly polarised, the apparatus preferably includes polarisation means for altering the polarisation of received radiation so as to align with the polarisation of the detector.

According to a third aspect of the invention, there is provided apparatus for imaging subcutaneous body temperatures, the apparatus having detector means sensitive to millimetre wave lengths of electromagnetic radiation and collector means for collecting such radiation travelling from an area of a body, wherein the apparatus includes calibration load means for emitting radiation, preferably thermal radiation, of a known intensity and is operable selectively to direct said radiation to the detector means to enable said calibration to occur.

Preferably, the collector means is operable to sweep said area over part of a body to be imaged, the calibration load means being situated in the pat[illegible] the deflector means. The calibration load means may have the other [illegible] or [illegible]geous features described in relation to the first and second aspects of [illegible]

According to a fourth aspect of the invention there is provided medical imaging apparatus for imaging subcutaneous body temperatures, the apparatus comprising detector means sensitive to millimetre wave electromagnetic radiation and for generating an output representative of said image, collector means for collecting said radiation from a selected body to be imaged and directing said radiation to the detector means, wherein the apparatus includes isolator situated in the means in the path of radiation to the detector means and operable to prevent interfering electromagnetic radiation generated by the detector from being emitted from the device via the collector means, whilst allowing received radiation to reach the detector means.

Preferably, the isolation means comprises a quasioptical isolator.

Brief Description of the Drawings

The invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of one embodiment of apparatus in accordance with all three aspects of the invention;

Figure 2 is a schematic view of elements within the apparatus when viewed in the direction of the arrow II of figure 1;

Figure 2A is a block diagram showing one of the elements shown in figure 2.

Figure 3 is a schematic end view of elements within the apparatus viewed in the direction of the arrow III in figure 1;

Figure 4 illustrates how [illegible] portion of the body to be imaged;

Figure 5 corresponds to figure 4, and illustrates how a modified version of the apparatus achieves the same effect;

Figure 6 is a schematic view corresponding to figure 2 of a modified embodiment of the apparatus;

Figures 7-9 illustrate the sensitivity distribution profile and beam pattern associated with the apparatus shown in figure 1;

Figure 10 is a schematic diagram illustrating how the sensitivity profile can be modified;

Figure 11 shows an alternative embodiment of the apparatus;

Figure 12 is a more detailed schematic view of an isolator forming part the embodiment shown in Figure 2;

Figure 13 is a view, corresponding to figure 2, of a further embodiment of apparatus, this embodiment having means for controlling the polarisation of the signal received by a detector in the apparatus;

Figure 14 shows visible, infrared and millimetre wave images of a part of a human hand.

Figure 15 is a sectional side view of one or two calibration loads for the apparatus;

Figure 16 is a plan view of the load;

Figure 17 is a sectional side view of the other calibration load;

Detailed Description

In figure 1, reference numeral 1 denotes the apparatus according to the invention, which is connected to electronic circuitry 2 for controlling and supplying electrical power to the apparatus 1 and also receiving image data from the apparatus 1 and displaying that data as an image on a computer 4. The apparatus 1 is positioned a few tens of centimeters directly above a table top 6 on which a part of the patient to be imaged (in this case the hand) is rested. The components of the apparatus 1, are contained within a housing 8 which is provided with a lower window (not shown) through which the apparatus can scan an area of the table top 6 in order to obtain the image. The apparatus scans the area in a succession of parallel lines, such as lines 10 and 12.

With reference to figure 2, the apparatus comprises a plane mirror 14 which is rotatably mounted about the axis 16 and connected to a motor (not shown) which, in use, rotates the mirror in the direction indicated by the arrow 18. The mirror 14 is in registry with the window and the housing 8, and folds the optical path, referenced 20, of the apparatus

through 90°, from a spot on the scan line (in this instance the line 12) towards a detector in the form of a 95 GHz heterodyne total power radiometer 22.

The mirror does not rotate at an exact rate due to unavoidable friction in the bearings etc. of the mirror mounting. To ensure that the orientation of the mirror is known for each captured data point, the scanning mechanism includes a patterned wheel and photosensor to record positional information in the form of two separate TTL channels. One channel indicates each complete revolution of the mirror, the other each increment of one degree in the mirror position. The second channel is used to trigger sample and hold acquisition of the radiometer output through suitable hardware. The final output is recorded directly onto computer via an ADC card.

The lines 24 and 26 indicate the edges of a collection path along which a millimetre wave electromagnetic radiation travels from a spot 25 to be imaged by the apparatus to the mirror 14. This light is reflected by the mirror through a quasioptical isolator 28 which is described in more detail with reference to figure 12.

Received radiation which passes through the isolator 28 then travels through a high density polyethylene focussing lens 40 and into a corrugated feedhorn 42 positioned immediately in front of the radiometer 22. The radiation focussed by the lens 40 on the feedhorn 42 takes the form of a substantially fundamental Gaussian mode beam which is converted by the horn 42 into a wave guide mode for reception by the radiometer 22.

The radiometer is shown is more detail in figure 2A, and comprises a mixer 3 for combining a received signed 5 with a signal from a local oscillator 7 and feeding the resultant intermediate frequency (IF) signal to an rf amplification and bandpass filtering stage 9. The stage 9 bandpass filters the IF signal and amplifies it to a level which can easily be rectified by a square law detector (in the form of a diode 11). The signal is then fed to an electronic amplification stage 15 in which it is integrated in a low pass filter and amplified to give an output voltage proportional to the brightness temperature of an area being imaged by the apparatus.

Certain types of radiometer, especially heterodyne designs, can leak local oscillator (LO) signals out of the input port of the mixer of the radiometer. This can be coupled out via the antenna towards the subject/target. If a subject is at long range as is the case for scene imaging, the amount of this LO leakage which is reflected back to the radiometer is negligible. However, with close-range subjects, a significant amount of power can be reflected back which couples coherently into the radiometer. This can degrade the performance of the radiometer by causing fluctuations in its sensitivity, and can be misinterpreted as radiation emitted by the target.

To avoid this effect, the isolator 28 prevents signals leaking out from the apparatus. The isolator can be located either between the feedhorn 42 and the radiometer 22 as shown in Figure 11 (typically in wave guide or microstrip technology), or in front of the feedhorn 42, which would be quasioptical technology. The latter option is the preferred one at millimetre wave lengths as it is easier to achieve low loss over a wide bandwidth necessary for good thermal sensitivity.

With reference to figure 12, the isolator comprises a diagonal polariser 30 which is in registry with the optical path 20 and a beam dump comprising a surface which is able to absorb radiation of the frequency of interest (referred to as "beam dump" 32). The diagonal polariser is orientated to allow a passage of light with a polarisation which is at 45° to that of light passed by a vertical polariser 34 which is also in the optical path 20 and in registry with a further beam dump 36. A Faraday rotator 38 is interposed between the two polarisers 30 and 34.

The isolator acts as a four port circulator in which two ports are terminated. Electromagnetic radiation of the desired frequency selected by the apparatus is passed through the isolator. However, any local oscillator leakage from the radiometer is sent to the beam dump 32. If there were any signal coming from the dump 32 it would go to the dump 36 and any stray signal from the dump 36 would go to the dump 32.

With reference to figure 3, as the mirror 14 rotates, the collection path is swept through 360°, and the scan line 12 is therefore in the form of a circumference swept out by the path. As can be seen from figure 3, the scan line 12 also intercepts two angularly spaced calibration loads 44 and 46 positioned above the rotating mirror 14, i.e. in that path of the scan or the collection path that does not include the target.

The calibration load 44 is shown in sectional side view in figure 15 and in plan view in figure 16. Figure 17 is a sectional side view, similar to figure 15, of the load 46. The load 44 comprises an emissive plate 48 formed from a continuous solid of a material having an emissivity close to unity which is mounted on a thermoelectric, Peltier heat pumping device 50 through a thin thermally conductive (eg metal) plate 52 which evens out any small scale temperature variations in the face of the Peltier device 50 (for example due individual semi-conductor junctions which generate the thermoelectric effect), and transfers a uniform temperature distribution to the back face of the plate of emissive material 48.

The material for the plate 48 [illegible] provide a sufficient thermal conductance to ensure its temperature can be controlled when in contact with the heat pumping device 50. The plate 48 should be thin enough to avoid the setting-up of too great a thermal gradient from the back to the front surface when the heat pumping device is operated. It is also preferable that the plate 48 has a front surface which is rough with respect to the wave length of operation as this will minimise any specular reflections from the surface. In the present example, this is achieved by having an outer surface in which regular pyramids (for example 54) are formed.

The thermoelectric device 50 is supported on a heatsink substrate 56 of a thermally conductive material (for example metal) to ensure that the face of the thermoelectric device 50 opposite the heat spreader plate 52 remains at the desired temperature. The temperature of the plate 48 is monitored by means of a thermometer 58 which is connected to temperature measurement control circuitry that measures the temperature of the plate 48.

The load 46 is identical to the load 44 except the Peltier device 50 is arranged to operate as thermoelectric cooling device for the emissive plate 48'.

It will be appreciated that each full revolution of the mirror 14 causes radiation from each of the calibration loads 44 and 46 in turn to be directed into the radiometer 22. Thus, the apparatus can be calibrated for each scanning line.

Description of preferred calibration method

The emissive material for the plates 48 and 48' is the thermal target which is used to calibrate the response of the radiometer. The emissive material is chosen to have an emissivity ε close to unity in the frequency range of operation ensuring that its brightness temperature T_B is very close to its physical temperature T_p, since

$$T_B \propto \varepsilon T_P$$

Having a high emissivity means the material is also a good absorber in the frequency range of interest.

The emissive material is a solid (rather than a porous structure as is the case for many electromagnetic absorbers) which has sufficient thermal conductance to ensure that its temperature can be controlled when in contact with a hot or cold plate. The emissive material is thin enough that when heated or cooled from the back surface there is not too great a thermal gradient from the back to the front surface. It is preferable that the emissive material has a front surface which is rough with respect to the wavelength of operation as this will minimise any specular reflections from the surface. To achieve this, the surface has an array of regular pyramids. A suitable emissive material could be a polymer, such as polypropylene, loaded with carbon particles.

The physical temperature of the emissive material is monitored with a thermometer (or thermocouple) embedded in the bulk of the material so that any variations in T_p are known and corrections can be made to the value of T_B used in the radiometric calibration.

Multiple thermometers may be used to monitor the spatial variations in temperature. A calibration/verification of the spatial thermal uniformity can be performed using an infrared radiometric imager,

The temperature of the emissive material is controlled by the action of the Peltier device which pumps heat from one side to another. The direction of heat flow is reversed when the direction of applied current is reversed.

The heatsink is a thermally conductive material (eg. metal) to which heat can be pumped in or out, thus ensuring the opposite face of the Peltier remains at the desired temperature.

The head spreader is a thin thermally conducting plate (e.g.metal) which evens out any small scale temperature variations on the face of the Peltier device (e.g. due to the individual semiconductor junctions which generate the thermoelectric effect) and transfers a uniform temperature distribution to the backface of the emissive material.

It is desirable to have a uniform temperature across the area of the calibration load with a minimum of thermal gradient towards the edges and corners. To achieve this, the heat spreader is preferably the same area as the emissive material, and as big as or slightly larger than the Peltier device.

For accurate radiometric calibration, it is desirable to have the thermal target filling the beam of the radiometer and having a uniform, known temperature over that area. The temperature should be constant during the time taken to make the calibration. Slow temporal variations in temperature can be monitored with a thermocouple (as described above . To perform calibration of the radiometer, it is preferable to use two thermal targets whose temperatures are above and below the range of temperatures expected in the real scene.The output of the radiometer (typically a voltage) is measured for the two calibration loads of known temperature thus yielding the sensitivity of the radiometer (e.g. in volts per Kelvin). When applied to the cylindrical scanning method described above, the calibration loads are sensed every rotation of the scanning mirror. This leads to a high

rate of repetitive calibration which can be used to reduce the effects of gain variations in the radiometer that cause fluctuations in sensitivity. Line-by-line calibration reduces artefacts in the image, such as stripes, caused by sensitivity fluctuations.

A large difference in temperature of the two loads is desirable provided that the response of the radiometer behaves predictably over that range. Preferably the radiometer should have a linear response to temperature.

In practice, the range of temperatures is limited by the performance of the Peltier devices. Additionally, when operating in normal atmospheric conditions, too cold a temperature will cause condensation and ice to form on the surface of the emissive material which could alter its apparent brightness temperature. For a radiometer measuring body temperatures (typically around 35 to 40°C), suggested calibration load temperatures could be 5 to 10°C for the cold load and 50 to 60°C for the hot load.

In the apparatus shown in figure 1, the housing 8 is mounted on a support (not shown) that facilitates controlled indexing movement of the housing 8 along the direction indicated by the arrow III. This direction is perpendicular to the scanning direction, and the indexing occurs at the most once for every revolution of the mirror 14. In order to reduce the effects of noise, the system can be arranged to average the results of a number of successive scans along each respective line. In this case, the mirror will undergo a number of revolutions (for example 5) at any given axial position before indexing occurs. This improves the signal to noise ratio of the device at the expense of the speed of image aquisition. With reference to figure 4, it will be appreciated that the apparatus acquires the image of a part of the body by obtaining image data from each successive one of a number of areas, for example area 60 in a single scanning line (line 1 figure 4) and then repeating the process for successive lines thereby building up an array of imaged areas, as denoted by the reference numeral 62 in figure 4.

The array of areas lies on a surface of a notional cylinder, and this correspondingly governs the plane of the captured image.

For any given position of the mirror 14, the apparatus is focused on a respective spot on the cylindrical surface, but the sensitivity of the apparatus to incident radiation across that spot will vary in the way shown in figures 7-9.

The lens 40 acts as focussing means which focuses the radiometer 22 on a spot on the cylindrical object plane (for a given position of the mirror 14). It is manifested in the collection path 24 – 26 as a convergence to a minimum width in the object plane R (figure 7), from where the path then diverges. The sensitivity profile of the collection path takes the form shown in figure 9, i.e. that of a fundamental mode Gaussian profile.

Figure 8 shows the sensitivity profile at various different points along the beam from a position some way in front of the point R (profile 100) to a position somewhere behind (profile 102). As can be seen, the profile retains its fundamental mode Gaussian form, but the width of the peak progressively decreases from the profile 100 to a minimum width at the focal plane R, whilst the peaks behind the focal plane R become progressively broader with increasing distance from the plane.

The Gaussian mode is preserved throughout the optical path, and enables the width of the collection path at the plane R to be comparable with the wave length of operation, the profile enabling the effects of diffraction to be anticipated or controlled.

The apparatus can be modified by the inclusion of an axicon, such as the axicon 104 in figure 10, in the optical path so as to convert the Gaussian sensitivity profile into a Bessel sensitivity profile. The axicon 104 can be interposed between the lens 40 and the mirror 14. The Bessel profile has a central peak which diffracts less over a given distance compared with a fundamental Gaussian profile of the same width. It is believed that this may improve the depth of field of the apparatus.

The choice of what frequency band to use for the imager depends on the number of factors and is a compromise between them. This choice is governed by the dielectric properties of

body tissue and how they vary with frequency. The most comprehensive publications on the dielectric properties of various tissue types are by Gabriel, Gabriel, Corthout & Lau who have surveyed existing data [1], made their own accurate measurements up to 20GHz[2] and proposed models [3] covering the frequency range 10Hz to 100GHz. Very little reliable data exists above 20GHz. Based on these models, one can investigate the trade-offs important to the imager design. In general a longer wavelength will penetrate through more tissue, whereas a shorter wavelength is desirable for good spatial resolution. Furthermore, shorter wavelengths are reflected less by the skin reducing complications due to reflection of thermal energy from the surroundings.

By considering the properties of different tissues using these models, the most likely frequency range for radiometric imaging of the body temperature is in the 10-100Hz range. Within that range, the 20-40GHz band will probably give a reasonable compromise between penetration depth and spatial resolution. The optimum band will not be known until different frequency ranges are tried as the models have yet to be accurately verified with experimental data above 20GHz.

Target values for penetration depth and spatial resolution are of the order of a few millimetres. Operation at higher frequencies (e.g. 90-100GHz) would yield better resolution (of the order of milimetres) but the penetration depth would reduce to fractions of a mm.

The 20-40GHz band is also preferred for the practical reason that components are readily available and reasonably affordable (due to their use for telecomms).

Radiometric detection of power (i.e. measuring brightness temperature) typically has a temperature sensitivity

$$\Delta T = \frac{T_{sys}}{\sqrt{B\tau}}$$

where T_{sys} the system noise temperature, B is the pre-detection bandwidth and τ is the integration time of the measurement.

From this one can see that for a radiometer of given noise temperature and bandwidth one can improve the temperature sensitivity (reduce ΔT) by increasing the integration time. This obviously trades-off against the image acquisition time. Typical integration times per pixel might be 1-10ms. This also governs the beam scanning rate.

One modified version of the apparatus is as shown in figure 6, many of the components of which correspond to the components shown in figure 2 and are therefore identified by the same reference numerals. The lens 40 and plane mirror 14 have been replaced by a fixed and rotating focussing mirror, respectively reference 150 and 152. These mirrors are curved so as to focus radiation, and can be formed of materials which dissipate less of the received radiation than a lens.

Another modified version of the apparatus is shown in figure 13, which again, uses the reference numerals of figure 2 to indicate corresponding components. As with the apparatus shown in figure 2, the radiometer 22 is a linearly polarised radiometer which collects signals reflected off a rotating mirror. The polarisation of the signals received from the lines scanned by the mirror can vary with the angle from which they are received. This may or may not be a problem depending upon what target is being sensed. For targets which are largely unpolarised (as body tissue probably is) it may not matter.

If, however, it is considered important to have a fixed polarisation at the target, this can be achieved with the addition of two quarter wave plates 160 and 162. A quarter wave plate converts linear polarisation to circular polarisation and vice-versa. If one is added in front of the receiving feedhorn, the system will receive circularly polarised radiation irrespective of scan angle. This is a function of the quarter wave plate 160. The quarter wave plate 162 is attached to the side of the rotating mirror, and rotates with it. Thus, if the input is linearly polarised, this is converted by the rotating plate 162 to a circularly polarised input,

and the second plate 160 converts the circularly polarised output from the plate 162 into linearly polarised radiation for acceptance by the feedhorn 42.

Figure 5 shows a modification to the apparatus in figure 1. In this case, the mirror 14 is no longer mounted for simple rotation about a single axis, but instead can rotate about the axis (16) and swing about a perpendicular axis (so that the mirror can be tilted in the direction indicated by the arrow 64). This approach causes the apparatus to scan a volume which is part of the surface of a sphere (i.e. curved in two planes).

REFERENCES

1. R Appleby, D.G. Gleed, R.N. Anderton and A.H. Lettington, "High Performance passive millimeter-wave imagaing". *Opt.Eng.*,32(6),pp1370-1373,1993.

2. D.M. Sheen, D.L. McMakin, and T.E. Hall, "Three-Dimensional Millimeter-Wave Imaging for Concealed Weapon Detection", *IEEE Trans.Microwave Theory Tech,* vol.49, no.9 pp 1581-1952, Sept 2001.

3) B. Bocquet, J.C. can de Velde, A. Mamouni, Y.Leroy, G.G[illegible] J. [illegible] and D. Delvalee, "Microwave Radiometric Imaging at 3 GHz f[illegible] Breast Tumours". *IEEE Trans. Microwave Theory Tech.* vol 38, no 6, pp 791-792, June 1990.

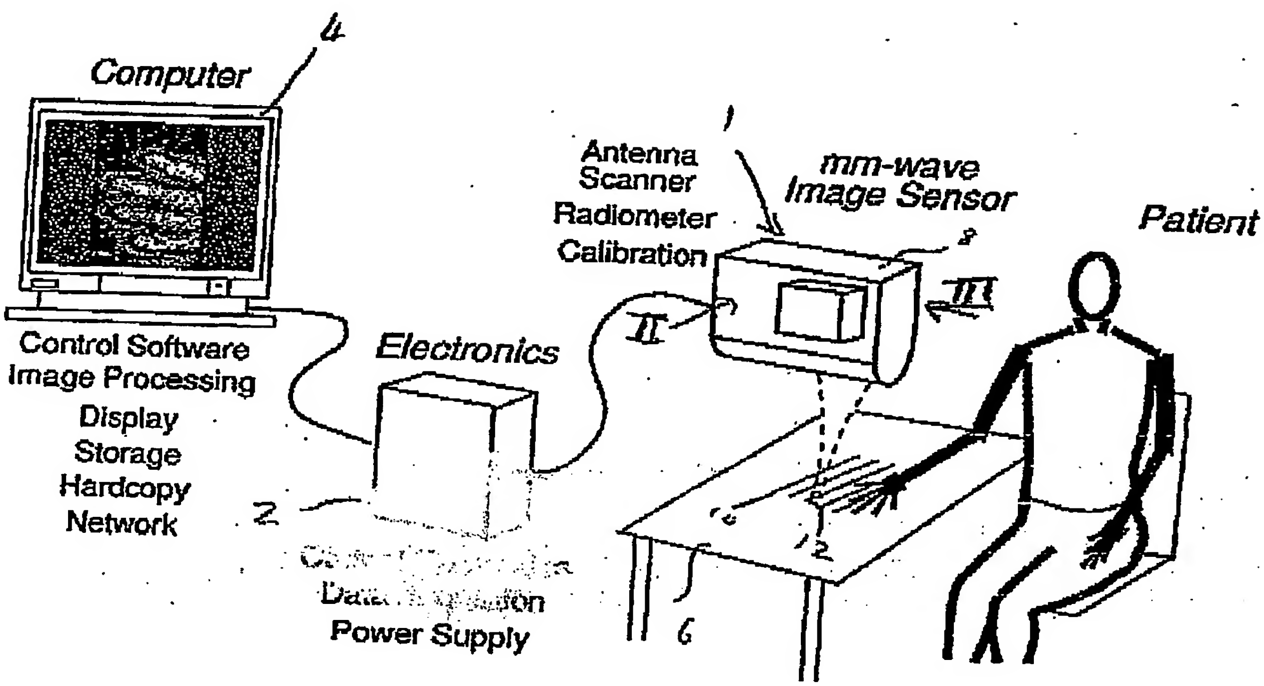


Fig. 1 : Block Diagram of Body Temperature Imaging System

Fig 2A

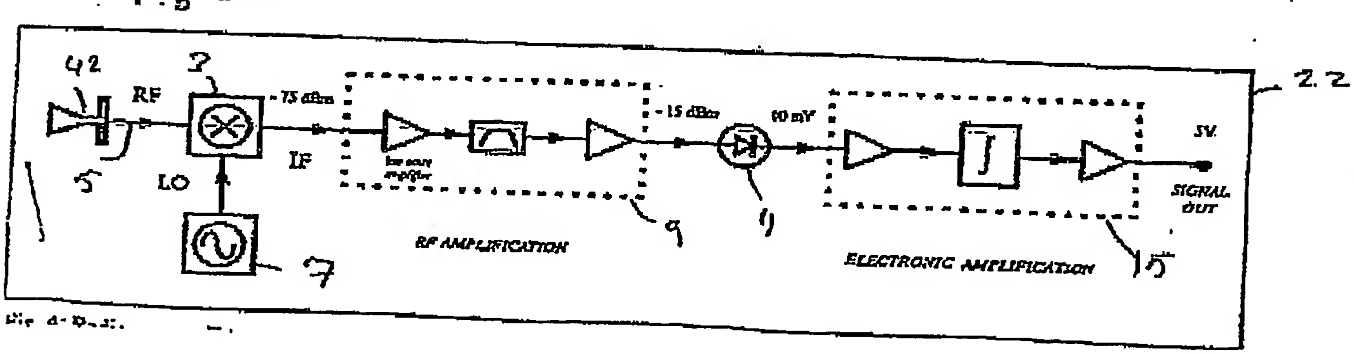


Fig 2

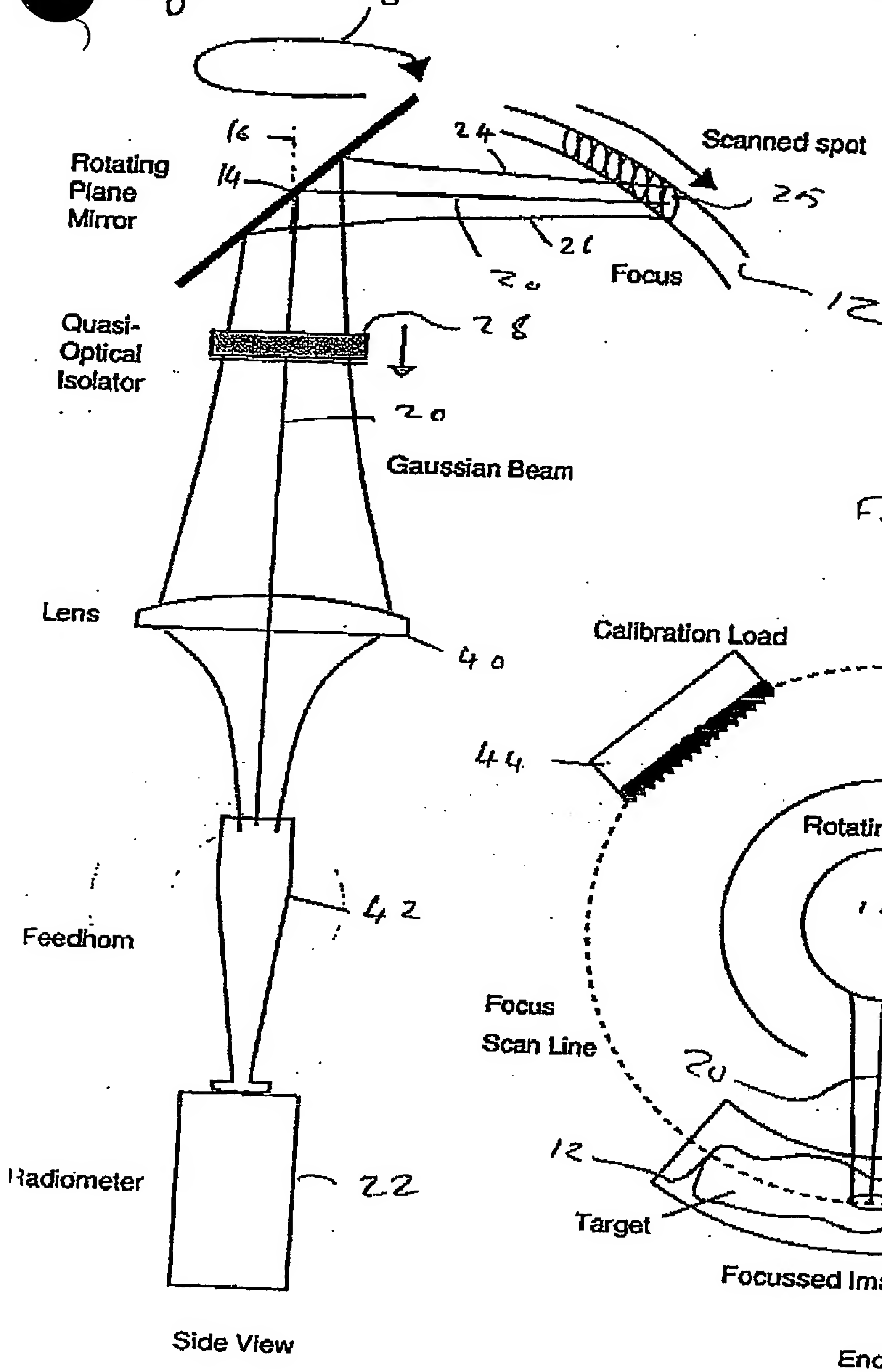

Rotating Plane Mirror
16
14
24
Scanned spot
25
21
20
Focus
12
Quasi-Optical Isolator
28
20
Gaussian Beam
Lens
40
Feedhorn
42
Radiometer
22
Side View

Fig 3

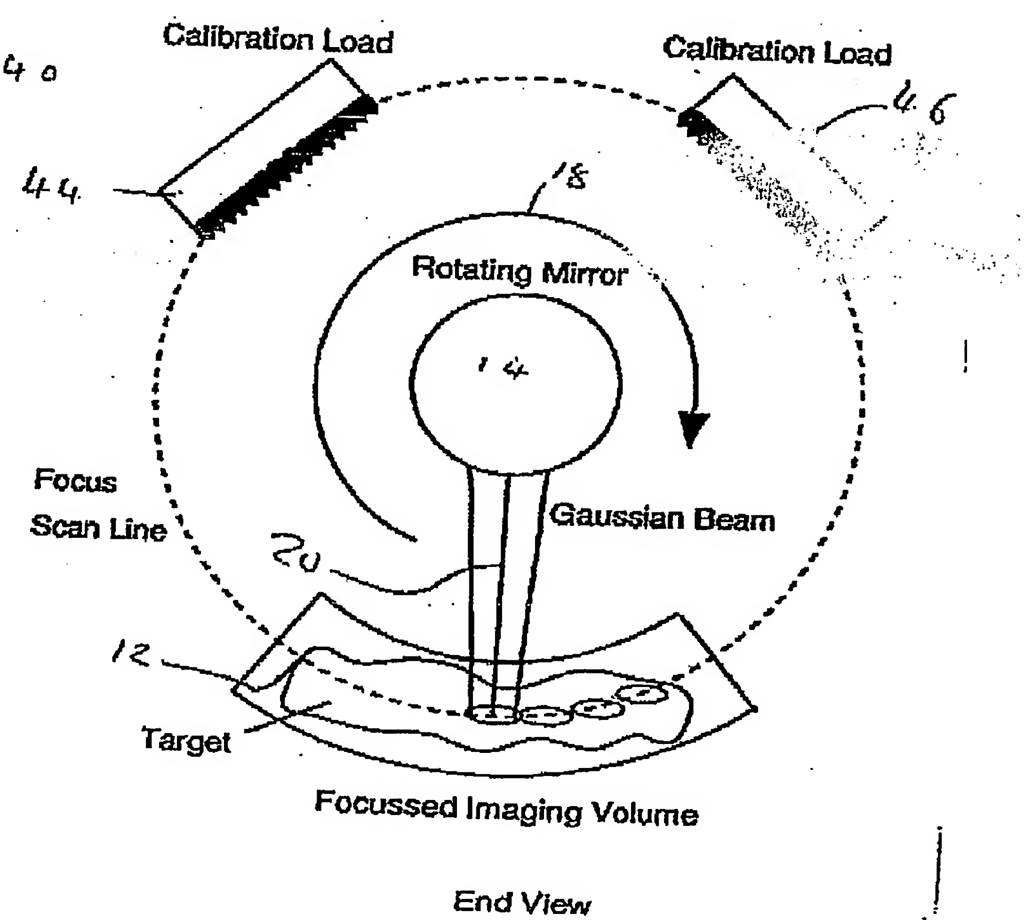

Calibration Load
Calibration Load
46
44
18
Rotating Mirror
14
Focus
Scan Line
Gaussian Beam
20
12
Target
Focussed Imaging Volume
End View

Fig 4

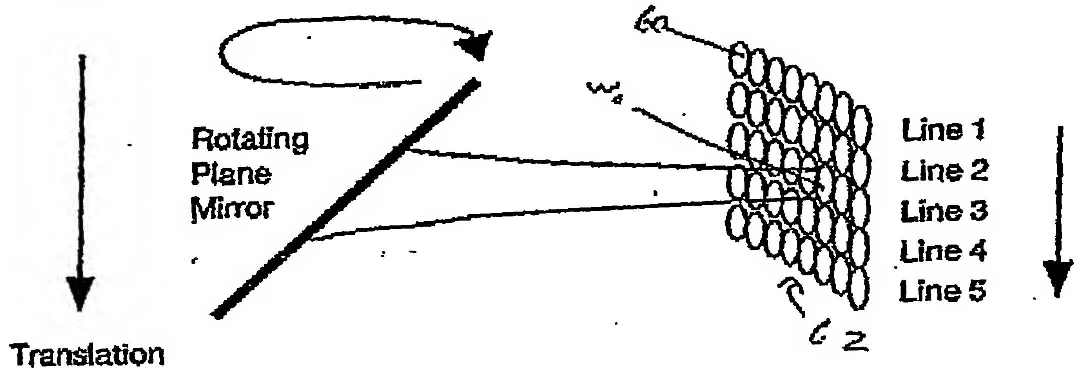
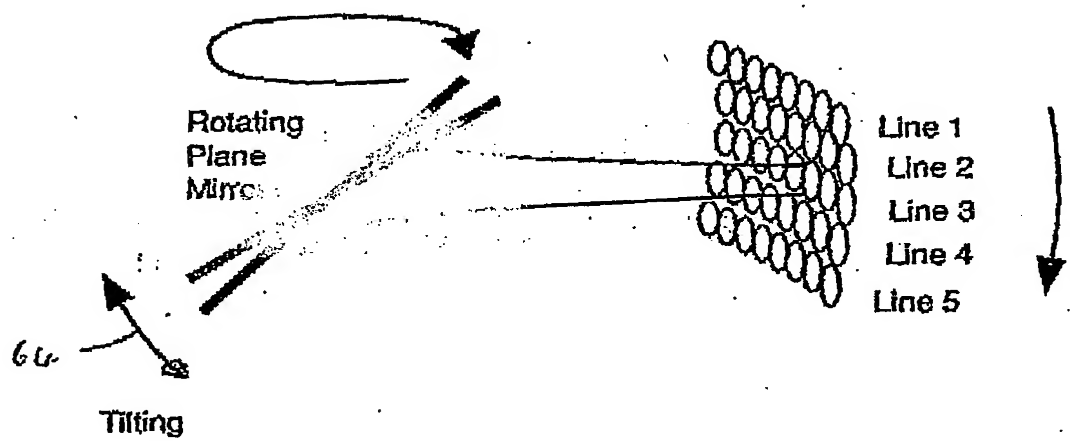


Fig 5



~~Fig. 3 :~~ Scanning in Two Dimensions - Alternative Methods

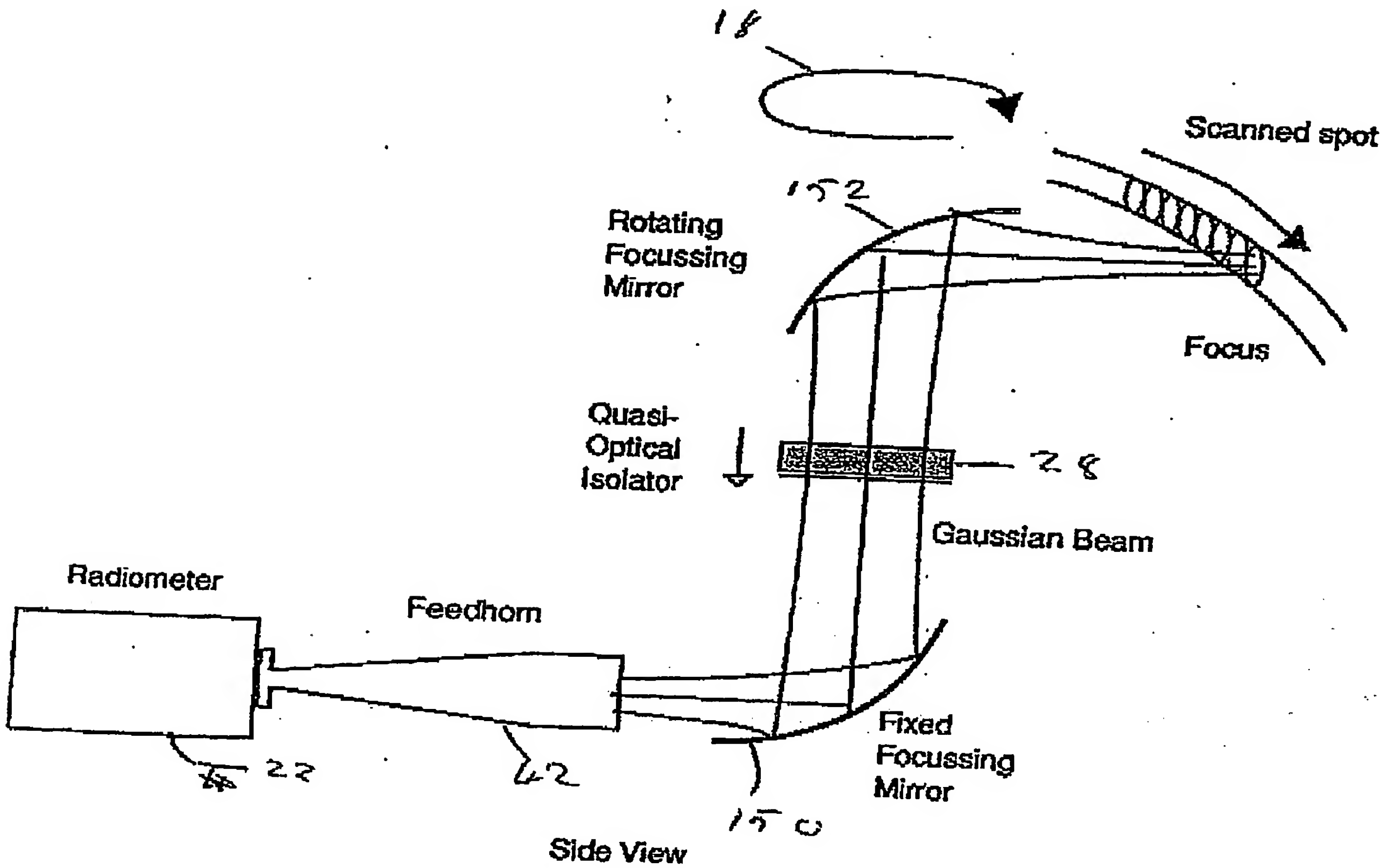
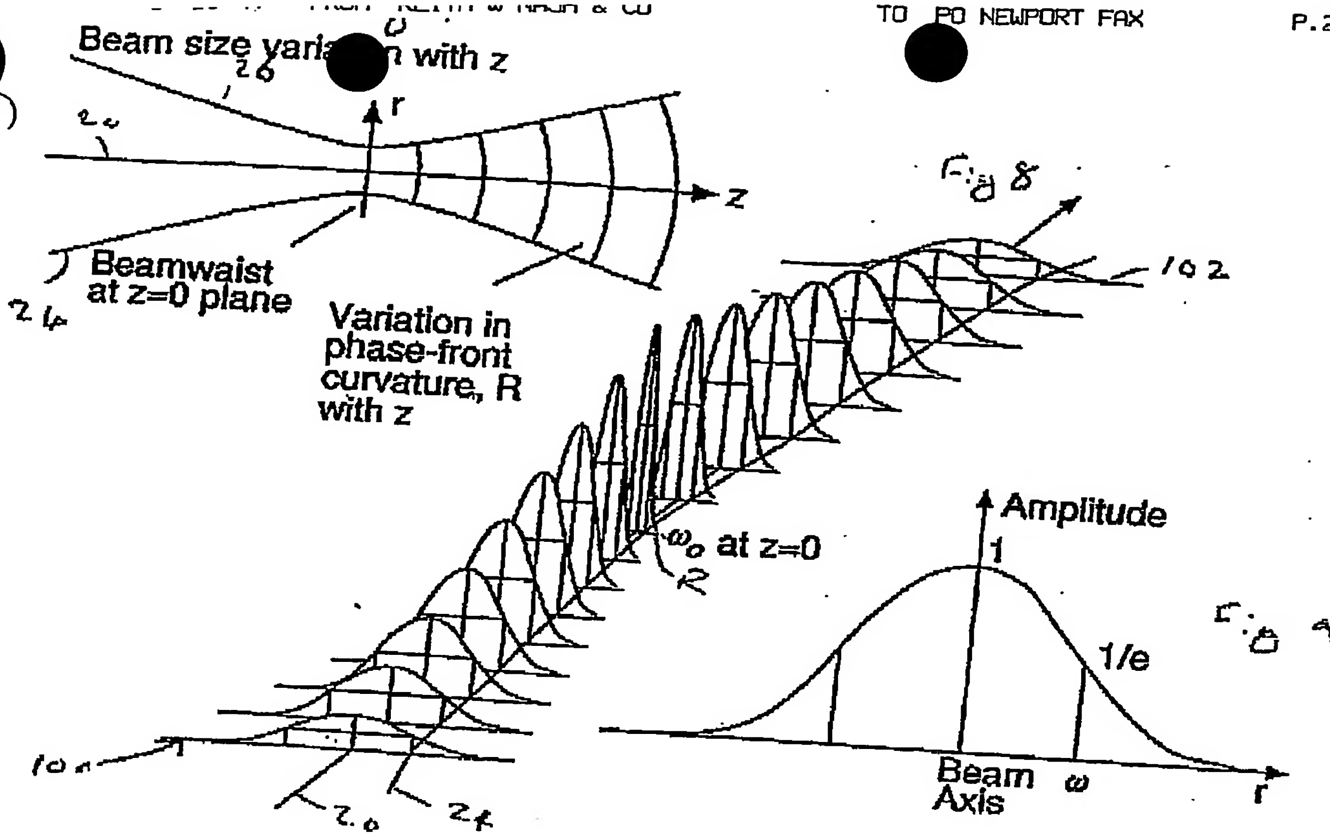
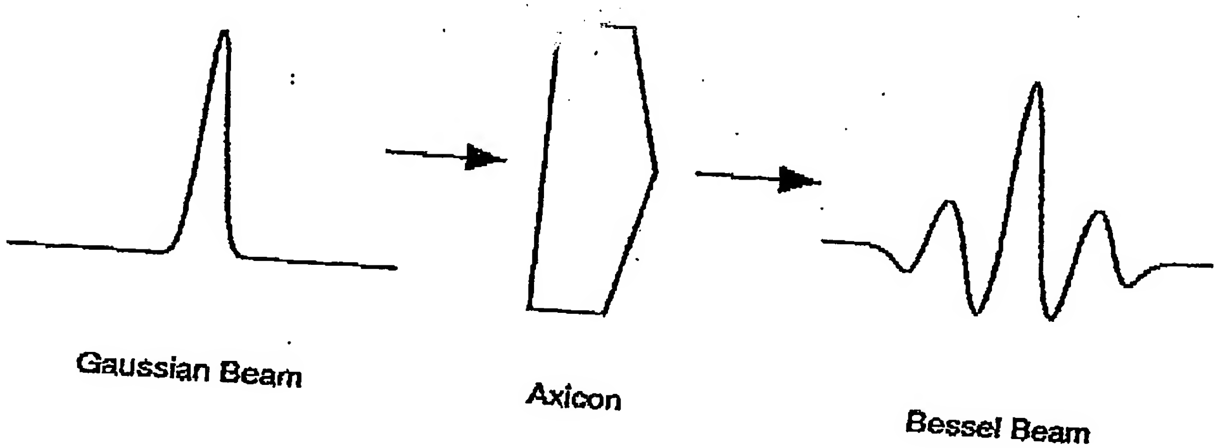


Fig. 6: Alternative Method of Focussing and Scanning



Fundamental Mode Gaussian Beam Propagation

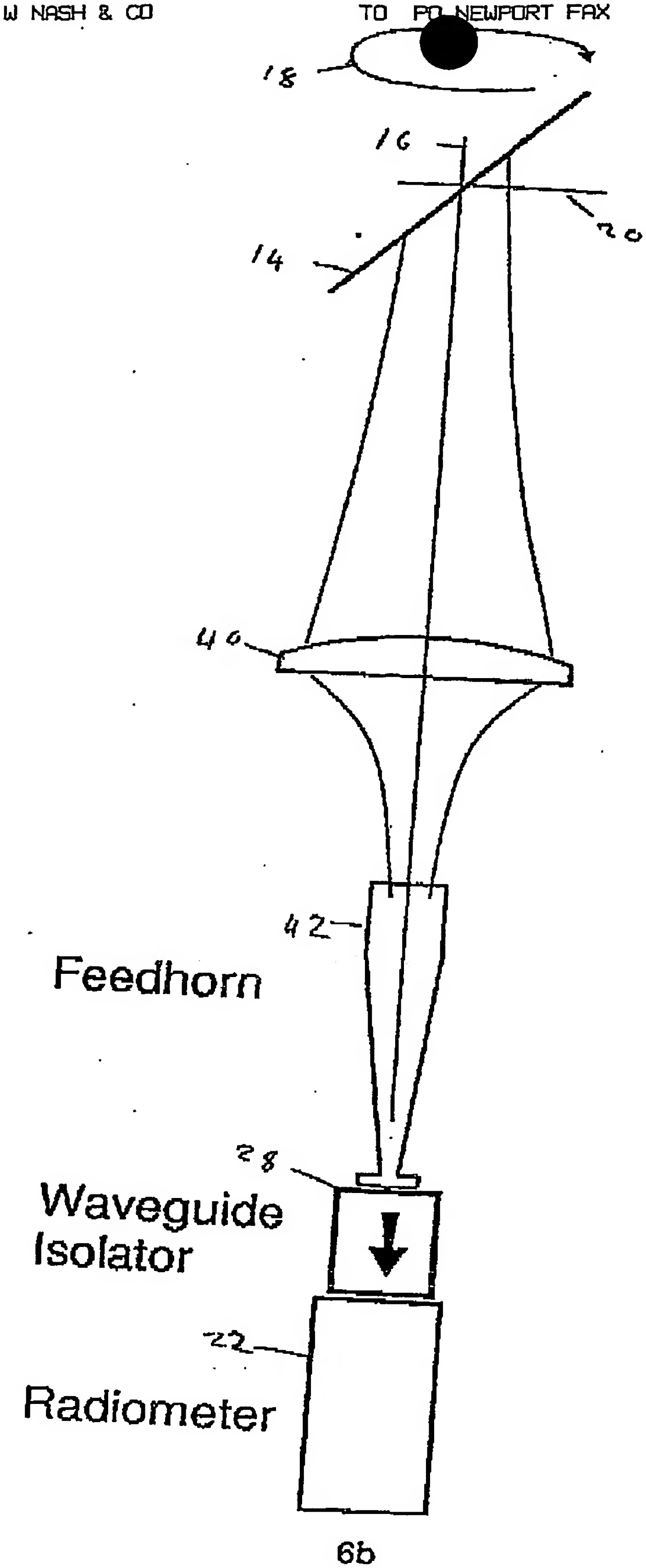
5a



Generation of a Bessel Beam

5b

Fig. ~~5~~ 10 : Gaussian and Bessel Beams



Front-End Isolation Fig 11

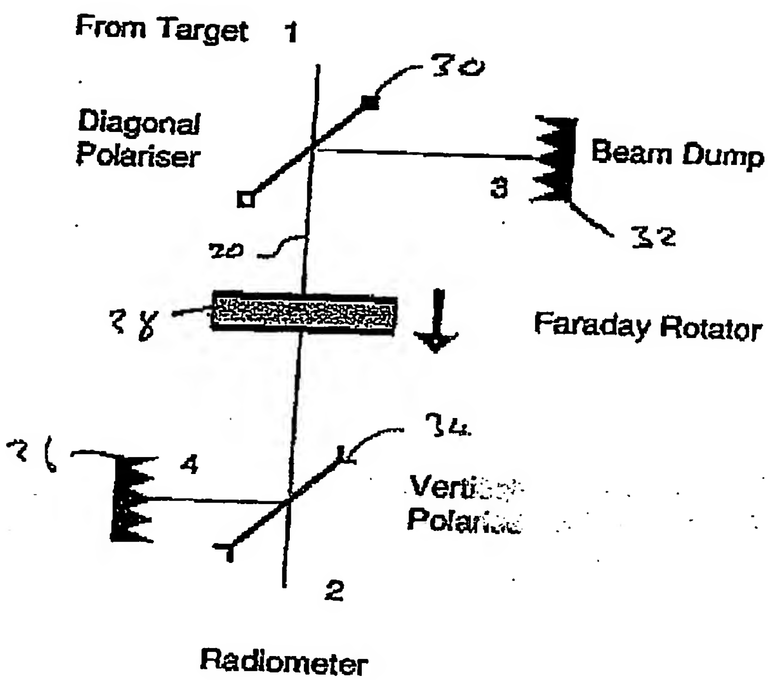


Fig 12 Quasi-Optical Isolator

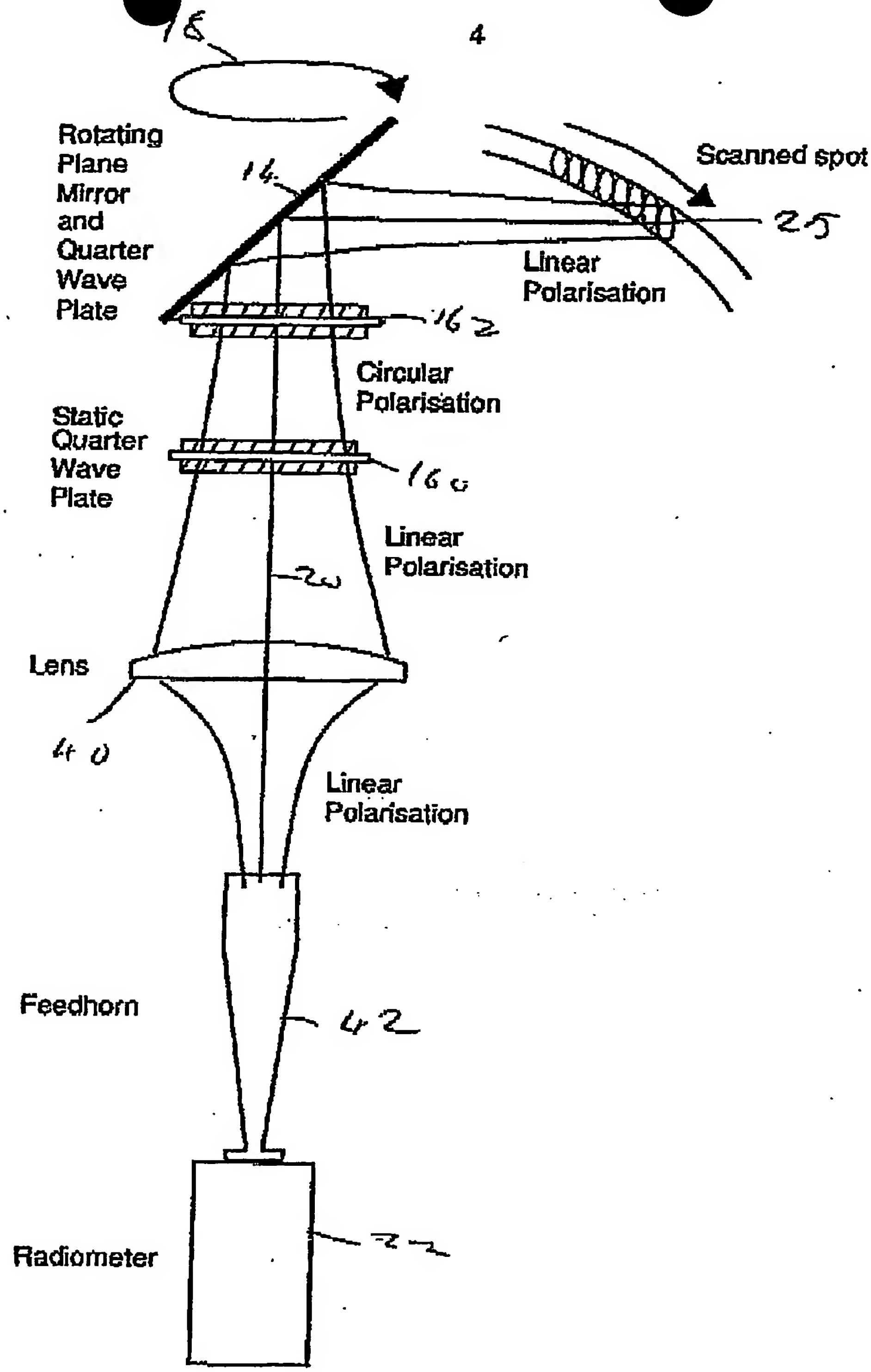
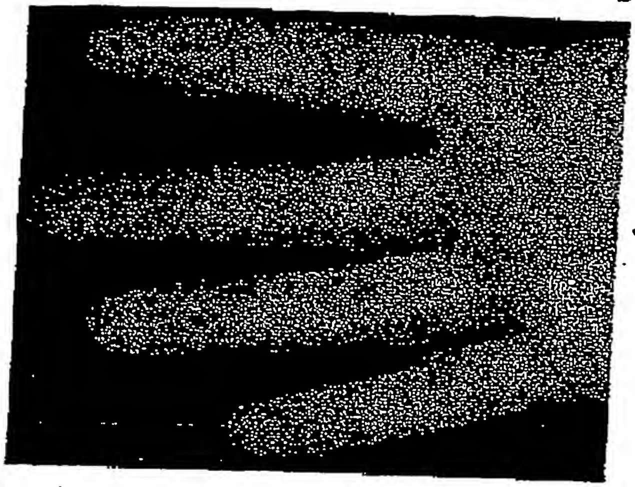


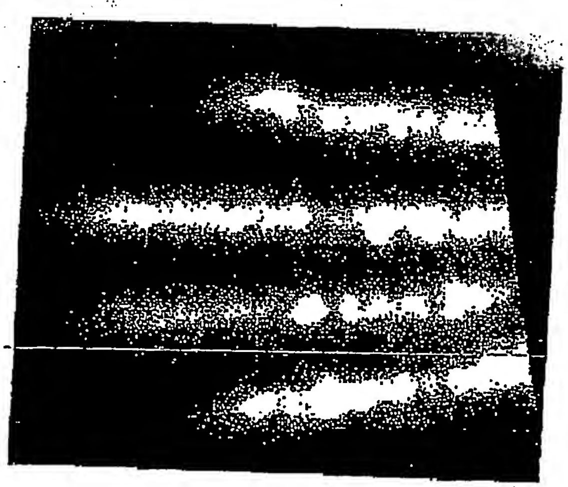
Fig. 13 Polarisation Control using Quarter Wave Plates

Fig 14



Visible

Infrared



mm-wave

~~Fig 2.2:~~ Visible, infrared and mm-wave images compared

Hot Calibration Load

Fig 15

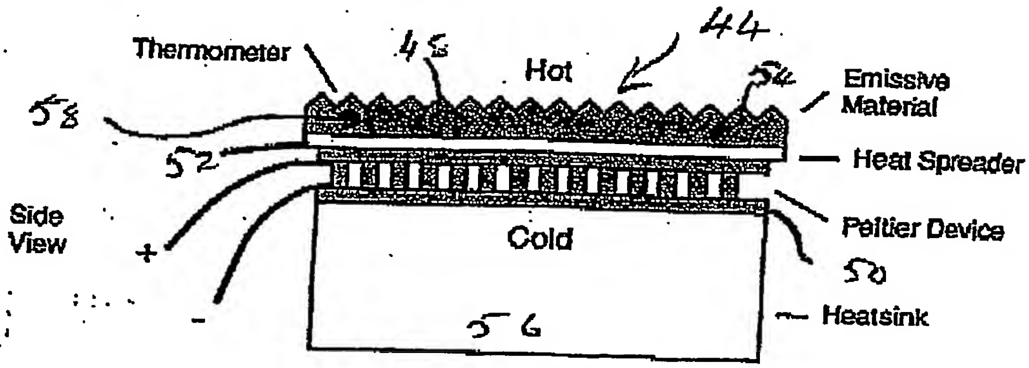
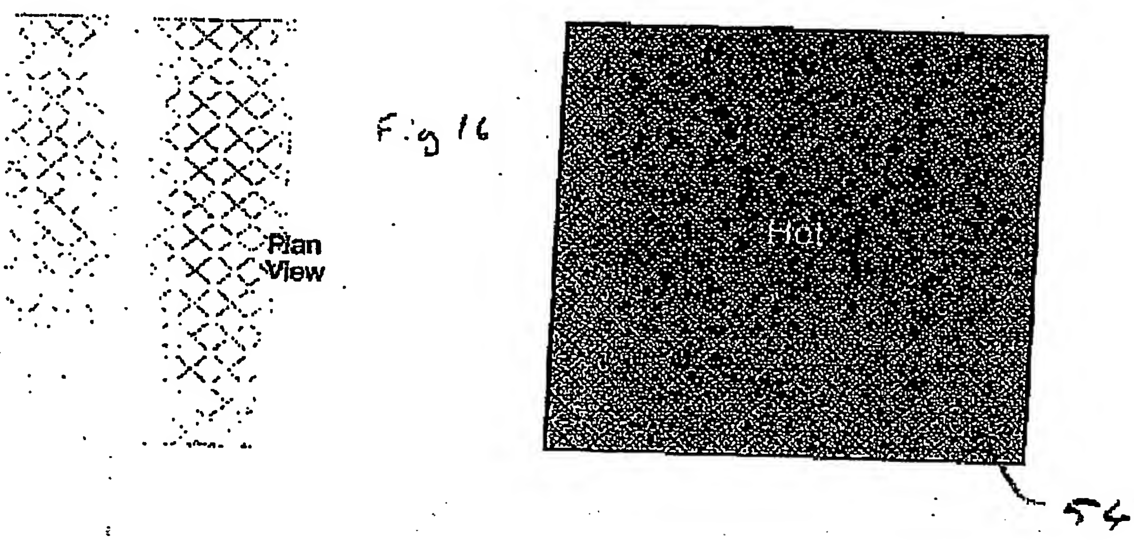


Fig 16



Cold Calibration Load

Cold

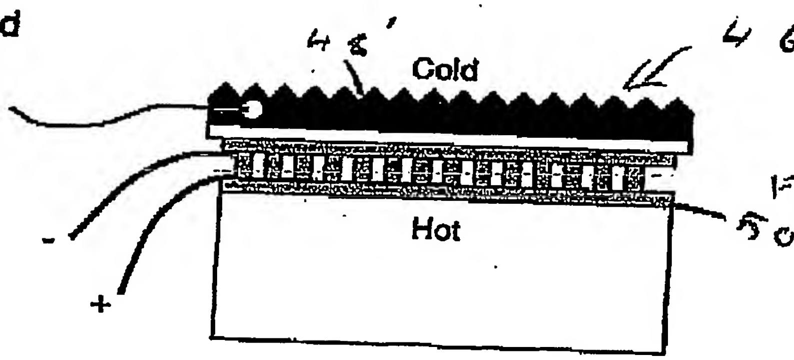


Fig 17

~~Fig. 8:~~ Suggested Structure for Preferred Calibration Loads

This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☑ FADED TEXT OR DRAWING
- ☑ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: ______________________

IMAGES ARE BEST AVAILABLE COPY.
As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.